UNIVERSITI PUTRA MALAYSIA

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By

ELFETORI F. ABDEWI

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DEDICATED TO

MY PARENTS, AND
MY WIFE

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I Certify that an Examination Committee has met on March 25, 1999 to conduct the final examination of Elfetori F. Abdewi on his Master of Science thesis entitled "Using Finite Element Method in Optimisation of Die Casting Design" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommended that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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ABBREVIATIONS AND NOMENCLATURES

FE : Finite Element

CAD : Computer Aided Design

CAA : Computer Aided Analysis

FEA : Finite Element Analysis

FEM : Finite Element Method

R_a : Factor of Roughness

LEFM : Linear Elastic Fracture Mechanics

CTOD : Crack Tip Opening Displacement

C : Carbon

E : Modulus of Elasticity (N/m^2)

ν : Poisson's ratio

ρ : Density (Kg/m^3)

σ^* : Equivalent stress (N/m^2)

σ_1 : Stress in X- direction (N/m^2)

σ_2 : Stress in Y- direction (N/m^2)

σ_3 : Stress in Z- direction (N/m^2)

c_p : Specific heat ($J/Kg\ ^oC$)

k : Thermal conductivity ($W/m\ ^oC$)

h : Convective heat transfer coefficient ($W/m^2\ ^oC$)

X : Product of the Grashof and Prandtl numbers

Y : Nusselt number

t : Temperature (^oC)

t_s : Surface temperature (^oC)

t_f : Film temperature (^oC)

Δt : Temperature difference (^oC)

g : Gravitational acceleration (m/s^2)

L : Length, fundamental unit of length (m)

μ : Dynamic viscosity (Kg/ms)

β : Temperature coefficient of thermal conductivity ($^oC^{-1}$)

C_{rm} : Raw material cost

C_{mc} : Machining cost

C_t : Total cost

q_x : Heat flow in X-direction (W)

q_y : Heat flow in Y-direction (W)

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in partial fulfilment of the requirements for the degree of Master of Science.

USING FINITE ELEMENT METHOD IN OPTIMISATION OF DIE CASTING DESIGN

By

ELFETORI F. ABDEWI

March 1999

Chairman: Shamsuddin bin Sulaiman, Assoc. Prof.

Faculty: Engineering

Die casting process is one of the widely used processes in the manufacturing area. It has the capability for high production rates with good strength, high quality parts with complex shapes. Die is the main factor which affects the cost of this process. Even when the process is semi or fully automated the cost of the die is proportionately high.

To design an optimum die, it has been understood that it is very difficult to achieve the target practically without prior prediction. It needs continuous monitoring of the process, starting from the first shot until the failure of the die. Even then it cannot be said that, the die has been optimised to produce a particular part. To decide so, several tests should be carried out on the same part. As this will be very costly, it would be unwise to do it. But in the presence of theoretical analysis, the number of tests will be reduced. For these reasons the Finite Element Analysis (FEA) would appear to be well suited to investigate the response of such system to structure and potential loading. Such a computational investigation is the subject of this research.

Commercially available FEA Software (LUSAS) has been used. A full Finite Element Analysis was carried out in order to achieve an optimum design, and to predict the die life. The analysis has been repeated several times for different elements to achieve the best possible design. Since casting is a repetitive manufacturing process, fatigue load was taken into consideration and analysis carried out for a high number of cycles.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai sebahagian syarat keperluan Ijazah Sarjana Sains

PENGGUNAAN KAEDAH UNSUR TERHINGGA DALAM PENGOPTIMUNAN REKABENTUK ACUAN PERUANGAN

Oleh

ELFETORI F.ABDEWI

March 1999

Pengerusi : Shamsuddin bin Sulaiman, Prof. Madya

Jabatan : Kejuruteraan

Proses tuangan acuan merupakan satu proses yang biasa digunakan dalam bidang pembuatan. Ia berkebolehan untuk menghasilkan produktiviti yang tinggi, kekuatan dan kualiti bahan yang baik serta dalam bentuk yang komplek. Acuan merupakan faktor utama di mana ia mempengaruhi kos proses ini. Kos acuan ini adalah tinggi samada dalam proses separuh atomasi auau sepenuhnya.

Untuk merekabentuk satu acuan yang optima, adalah jelas bahawa ini adalah susah untuk mencapai matlamat ini secara praktikal tanpa anggaran terlebih dahulu. Ia memerlukan pemantauan yang berterusan di mana ia bermula dari produk pertama hingga ke kegagalan acuan. Untuk tujuan ini, beberapa ujian perlu dijalankan pada produk ini. Disebabkan oleh kosnya yang tinggi, adalah tidak sesuai untuk melakukan demikian.

Tetapi dengan kehadiran analisis teori, bilangan ujian ini boleh dikurangkan. Atas sebab-sebab itu, Analisa Unsur Terhingga (FEA) adalah sesuai

untuk mengkaji kesan sistem ini terhadap struktur dan beban. Dengan ini kajian dengan menggunakan komputer adalah subjek kepada penyelidikan ini.

Aturcara "FEA" komersial iaitu LUSAS telah dipilih, dan analisis Unsur Terhingga telah dijalankan untuk mencapai rekabentuk yang optima dan menjangka hayat acuan. Analisis tersebut diulangi beberapa kali bagi unsur-unsur yang berlainan dalam mencapai rekabentuk yang terbaik. Disebabkan tuangan adalah satu teknik proses pembuatan penuangan, daya lesu perlu dipertimbangkan dan analisiss ini dijalankan dalam kitaran yang banyak.

CHAPTER I

INTRODUCTION

Casting process is one of several different methods, which can shape materials into useful products. Making parts by casting molten metal into a mould and letting it solidifies is a logical choice. Indeed, casting is among the oldest methods of manufacturing and was first used in about 4000 B.C. to make ornaments, copper arrowheads, and various other objects (Kalpakjian, 1995).

One of man's ancient applications of the casting process had been mentioned clearly in the Holy Qur'an:

> "*Bring me blocks of iron. At length, when he had filled up the space between the two steep mountainsides, he said, Blow (with your bellows), then, when he had made it (red) as fire, he said: bring me, that I may pour over it, molten lead*" (Abdullah Yusuf Ali, 1994).

This proves without any doubt that this process is as old as history.

Basically, metal-casting processes involve the introduction of molten metal into a mould cavity where, upon solidification, the metal takes the shape of the cavity. The casting process is thus capable of producing intricate shapes in a single piece, including those with internal cavities. Very large or hollow parts can be produced economically by the casting technique.

Of the variants of die casting, one of the widely used processes is pressure die casting. This process is classified as a permanent casting process. It has the capability for high production rates with good strength, high quality parts with complex shapes. It involves forcing the molten metal into the cavity at a high pressure. Products made by pressure die casting have excellent dimensional accuracy and surface finish as well as being economically viable, especially for repetitive casting.

Since die is the main is part of this process which determines the economics of the whole process, die life itself is an important parameter for measuring the economic efficiency of pressure die casting. Therefore this work focuses on the means of optimising die design to produce products with high dimensional quality and high production rates.

There are many parameters affecting die life. Given this multiplicity, it is near impossible to calculate and analyse these parameters in the absence of high-speed computers. Today, computers allow designs to be assessed much more quickly and easily. A complex engineering design can be evaluated by exact mathematical models. Finite Element Method is a suitable technique for such investigations. Different FE codes for different applications are available. LUSAS was identified as one of the codes suitably applicable to cover all the analysis and optimisation needed for this research.

Since we cannot calculate the response of a complex shape to any external loading, we must divide the complex shape up into a number of smaller and simpler shapes. These are the finite elements that give the method its name. The shape of each finite element is defined by the co-ordinates of its nodes. Adjoining elements with common nodes will interact (Mystro User Guide, 1995). Thus, one of the main aims of this work was to draw the path of the die design, and provide the design procedure for any die shape.

Problem Definition and Scope of Work

The present work is an extension of previous work done by Abedin, (1997). That work focused on developing a CAD/CAA system, which is an integration of CAD and CAA techniques for the casting process, and for testing the developed system to produce an anchor using the pressure die casting process. The analysis carried out by Abedin, (1997) was mainly on heat flow and fluid flow of the molten metal, while the die itself was assumed to be strong enough to handle the process safely.

The approach used for this problem of ensuring sufficient strength of die was through a formal numerical optimisation procedure. As shown in Figure 1, the procedure starts with the initial die proposed by Abedin, (1997). This die needs to be examined or tested as to its ability for sustaining the exerted loads during the process without any failure for a sufficient number of cycles. Full analysis and optimisation were carried out. It includes thermal load analysis, structural load analysis, and geometrical load analysis. The output of all the analysed processes is the modified die. Failure tests were carried out on the modified die in order to check its validity before being able to finally design a die that has the ability to withstand all the loads exerted through out the process.

Objectives

The present study focuses on designing an optimum die for a pressure die casting process. The product to be produced is an anchor. In this respect the aims of the current project are:

1. To create a finite element model of the die to be designed.
2. To generate a finite element analysis with different element types.
3. Evaluating the process by varying single parameters until the optimum design is achieved.
4. To find out the thermal stresses which affect the die life.
5. To analyse the fatigue loads and predict the die life.
6. To develop a technique which can aid in the optimum design of such systems.

Layout of Thesis

The thesis is divided into six chapters. The first chapter contains the introduction and the objectives of the research. Literature review is presented in Chapter II. Chapter III deals with design optimisation of the die used in casting, which includes die geometry analysis, thermal load analysis, and clamping force analysis. Chapter IV represents the results and discussion. Chapter V summarised the discussion of the whole thesis. Conclusions and recommendations of the overall research are presented in Chapter VI.

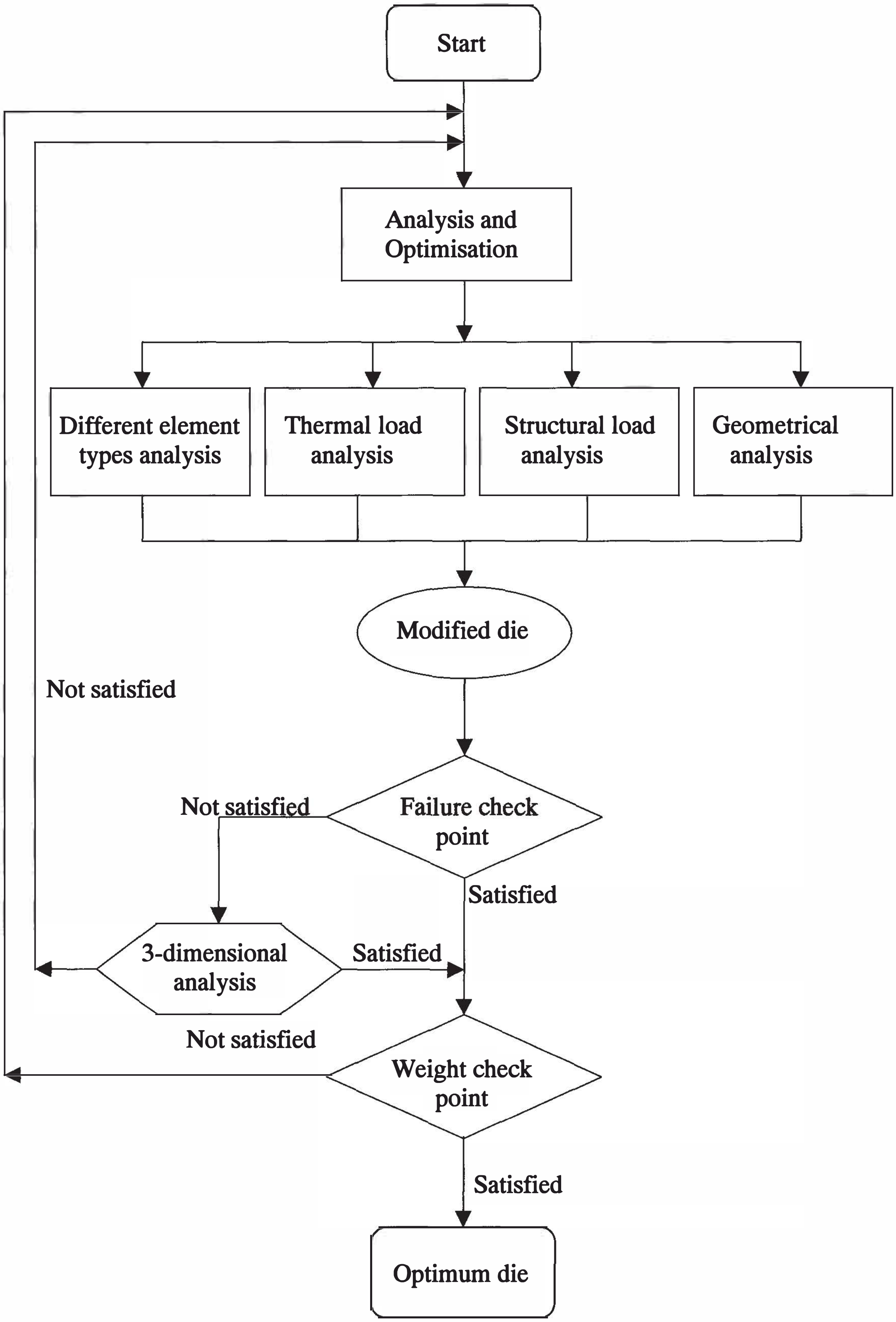

Figure 1: Research flowchart

CHAPTER II

LITERATURE REVIEW

In this chapter, important factors that influence the analysis and optimisation of the die casting process are reviewed. The more pertinent research work in the field of die casting design are summarised. The finite element method is discussed. The mechanics of fracture, die life prediction, and fatigue crack has been extensively reviewed.

Fackeldey et al., (1995) have presented an in-house 3-dimensional finite element model. They used the finite element program, CASTS for evaluating the process by varying single parameters, i.e. the initial temperature as well as the mould geometry. This leads to an optimisation of the process and allows an assessment of the mould life.

Guleyupoglu et al., (1995) described a methodology to optimise the casting riser design. A genetic algorithm was used for simplicity as well as robustness. Moreover, values of selected riser design parameters were examined using a modulus based approach to optimise the riser yield while achieving functional performance. They showed that the geometric modulus approach is a viable method of evaluating the efficiency of a riser and optimising its design.

Byrne P. E. et al., (1995) illustrated a couple of design sensitivity analysis and numerical optimisation with process simulation to improve the design of castings and weldments. They derived a mathematical expression for explicit sensitivity analysis of weakly coupled thermal stress systems. In an example, they used thermal analysis to determine an optimal riser design for a steel hammer casting.

Richard L. et al., (1993) demonstrated the results of optimising production of a die casting by numerical simulation of die filling and solidification. A model was presented and the simulated results were compared with the actual results. Their work demonstrated that the application of numerical simulation in the die design is extremely helpful in optimising die casting production.

Historical Background of the Pressure Die-Casting Process

Pressure die-casting belongs to the family of casting processes, which utilise a permanent mould. Other processes in this family include gravity die-casting and low pressure die-casting. Historically, gravity die casting predates the other two processes by several thousand years. Archaeological evidence would suggest that a form of gravity die casting was in use during the Bronze Age period for the manufacture of axeheads, the mould material being stone (Upton, 1982).

Like many technological processes, the origins of pressure die casting are not known with any degree of certainty. However it is generally considered that